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Research & Development Center

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Thermal Oscar Design Test Report and Prototype

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16. Abstract (MAXIMUM 200 WORDS)

The purpose of this Coast Guard R&D Center initiative was to design a target for use in at-sea sensor testing that has the infrared (IR) characteristics of a person in the water (PIW). The target was also designed to be inexpensive and easy enough to fabricate that the parts could be purchased and assembled by a CG unit for IR sensor training, and rugged enough to sustain repeated open-ocean testing.

Multiple prototypes were tested and evaluated with respect to temperature replication (as measured by hand-held and ship borne IR cameras, and comparing with human PIWs), operational life (again measured via the sensor), target replication (size, shape and perspective as measured by comparison with pictures of human PIWs), cost (Objective cost $1000) and durability. These characteristics were assessed during deployment, operation, retrieval and transport.

A prototype was tested that provides a reliable four-hour thermal target which approximates the IR signature of a PIW and is durable enough for at-sea testing, at an affordable cost.

The product will be used to facilitate future RDC IR sensor T&E efforts and could conceivably be used by operational CG units to fabricate Thermal Oscars for IR sensor training purposes.

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EXECUTIVE SUMMARY

The use of infrared sensors for search and rescue and near ship surveillance of targets such as swimmers or persons in the water (PIW) is a relatively new application. Historically, infrared sensors on surface units have been used for optical weapon targeting systems, or search and track systems for incoming weapons. Forward-Looking Infrared (FLIR) systems are now installed on most major CG surface and air units and becoming commonplace on small boats as well. These CG FLIR systems require operationally-realistic testing to characterize their mission performance and CG FLIR operators require training to become proficient at detecting challenging targets such as PIWs.

Operational testing of these sensors requires a thermally-appropriate target, presently involving human swimmers in the open ocean. Testing can be logistically difficult, and potentially unsafe, especially if an unforeseen event interferes with an at-sea test (sudden weather change, non-participant vessel interference, inherent dangers of at sea deployment and retrieval of swimmers) particularly in challenging sea states.

Current thermal "manikins" developed by the Department of Defense (DoD) for R&D efforts are cost-prohibitive, as they are usually designed to emulate human emissivity in changing environmental conditions, and for the entire human body. The manikins also do not lend themselves well to at-sea testing; being vulnerable to salt water and rough handling expected during deployment and retrieval by CG units.

The conceptual goal of this Coast Guard R&D Center initiative was to develop an IR target that was inexpensive, durable enough for at-sea testing and provided a thermal signature equivalent to that of a PIW for purposes of detection by a CG unit conducting search and rescue or swimmer surveillance.

The empirical effort was to design an infrared target that matched the signature (size and ΔT) of PIWs, at an affordable cost to a CG unit, both in time of fabrication and in materials cost. Developmental testing of thermal infrared targets for temperature measurement and imagery was accomplished by using a calibrated long-wave infrared (LWIR) FLIR® Systems B400 handheld camera. Operational testing was performed at sea onboard CGC Thetis (WMEC 910) using a mid-wave infrared (MWIR) system, the Shipboard Infrared Visual Sensor System (SIRVSS). The FLIR® Systems B400 handheld was also used at sea, primarily for temperature assessment of individual targets. The tests compared the targets (known as "Thermal Oscars") to live humans.

A successful Thermal Oscar design was fabricated and tested in swimming pool, dockside, and open-ocean environments. Design details, component lists and fabrication instructions are included in this report along with the test results. This capability will provide a safe and affordable means of testing IR sensors against PIW targets. Future testing using these targets would provide improved mission planning data and validate guidance for IR sensor operation to improve PIW search mission performance, especially at night.

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

COTS	Commercial Off-The-Shelf
CTF	Contrast Threshold Function
ΔL	Differential Radiance
ΔT	Differential Temperature
°F	Degrees Fahrenheit
FLIR	Forward Looking Infra-Red
GTT	Gradient Thermal Target
HDV	Heated Diving Vest
IR	Infrared
LWIR	Long-Wave Infrared
Manikin	Human-like Mannequin for field use.
MRTD	Minimum Resolvable Temperature Difference
MWIR	Medium-Wave Infrared
NMI	Nautical Mile
OSCAR	Traditional name for man overboard dummy
OTH	Over-The-Horizon
PFD	Personnel Floatation Device
PIW	Person In the Water
RDC	Research and Development Center
RHIB	Rigid-Hull Inflatable Boat
SIRVSS	Shipboard Infrared Visual Sensor System
WMEC	Medium Endurance Cutter

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1 INTRODUCTION

1.1 Background

During FY 2009 the Aviation Branch of the U.S. Coast Guard Research and Development Center (RDC) took on the challenge of addressing an anticipated need for a low-cost target able to simulate a person in the water (PIW) for use in testing the performance of Coast Guard thermal Infra-red (IR) sensors. Such a device would facilitate operationally-realistic testing of the newest thermal IR systems onboard Coast Guard vessels and aircraft, without the burden of tasking Coast Guard swimmers to fill the need for search targets. This approach would reduce the logistical costs and safety risks of operational sensor testing while increasing the amount of data obtained from expensive at-sea test time.

1.1.1 Infrared Sensors for Detecting a PIW At Sea

The use of the infrared spectrum as a tool for nighttime detection of human targets was developed primarily with land-based targets in mind. Night vision scopes in the field evolved from low-light vision to being able to detect targets in complete darkness, via thermal infrared. Forward-looking Infrared (FLIR) sensors now come in a variety of detector packages, with resolution and price in a direct relationship. This technology is available onboard many USCG air and surface platforms.

Army researchers developed models for land-based IR target probability of detection, and refined them to take into account factors such as camouflage (O'Kane et al, 2004). The model developed by the Army was used as a basis for detection of targets in the water, where the existence of "solar clutter", which is solar reflection of the water creating an above-threshold image on the display, was found to be a key source of clutter during daytime use (thermal imagers do not directly measure temperature differences, but rather sense radiance (L) and differential radiance (ΔL) (Krapels 2007). The reflected component of the water is a minor consideration at night, allowing the (surface) water temperature itself to become the background threshold against which targets of interest must be detected. Water is essentially opaque to an infrared sensor, thus a contrast must exist between surface water temps and the target for detection. Mixing of sub-surface and surface water can cause clutter in higher seas states, especially when whitecaps are present.

1.1.2 PIW Thermal Characteristics

Research has found that immersion in cold water causes extreme variation in human thermal signature, depending on a multitude of factors, such as body type, clothing, etc. (Wissler, 2003). The human body also varies in its thermal signature when subjected to atmospheric considerations, including solar input from sunshine, wind input (increasing or reducing evaporative factors), relative humidity, and air temperature (Mak, et al, 2008). Eventually the human body will go into a state of hypothermia if left in the ocean long enough, even at relatively benign temperatures (Wissler 2003). To build a thermally-representative PIW target ("Thermal Oscar") that would be able to vary its temperature ranges to match all possible encountered environments was deemed to be beyond the scope of the prototype design, due to cost objectives. The chief considerations of the Thermal Oscar were to be: 1) an approximation of the surface temperature of human head/shoulders in the water, and 2) the profile of the Oscar in the water needed to reasonably approximate a PIW's for size and buoyancy. The batteries of the Oscar will eventually run down, and create a hypothermic-like curve of temperature, but accurate hypothermic temperature re-creation was not a consideration for the current prototype, again due to cost objectives.

1.2 Objectives and Measures

1.2.1 Functional Objectives

The requirements for Thermal Oscar included: 1) realism of the target in comparison with a PIW, both in temperature measurement and in the displayed image from the sensor, 2) easily deployed and retrieved, and 3) inexpensive to build and test, while being safe and reliable to use (approximately $1K; and able to be used multiple times).

1.2.2 Physical Objectives

The physical objective was to create a device that generated a thermal signature similar to that of a human survivor in the water, including a physical cross-section similar to that of a PIW. The design was to be made rugged enough to be able to withstand hours in an open-water environment but cheap enough to be considered expendable. The device must be able to be recreated by CG personnel from a set list of parts and assembly instructions.

1.2.3 Measures of Effectiveness

The Thermal Oscar design needed to have the same buoyancy and visible cross-section as a human when viewed by a thermal infrared sensor.

1.2.4 Measures of Performance

Temperatures/displayed thermal image of the target should be very similar to a human PIW in the same water environment (ideally within a few degrees Fahrenheit above or below a human PIW temperature). This signature must persist for a minimum of four hours when deployed at sea in moderate water temperatures.

1.2.5 Measures of Suitability

Preparation, deployment, retrieval and re-use should be considered simple to a technician, using basic skills.

2 PROTOTYPE DESIGNS AND TESTING

Several prototype ideas were initially investigated as a solution, from the simplest designs of a head-shaped object filled with heated gel-packs to sophisticated manikins with thermal regulation circuitry. Five designs were investigated for initial testing, of which three; a resistive-circuit powered heated water unit, a flexible neoprene heater, and a gel-pack design were eliminated for failure to meet power and duration threshold objectives reliably. The two remaining prototypes were named the Gradient Thermal Target (GTT) and the Heated Diving Vest (HDV) designs, based on their commercial application.

2.1 Gradient Thermal Target (GTT) Design

The initial leading design was based on a commercial off-the shelf (COTS) thermal infantry target comprised of a nichrome wire mesh modified in size, shape, and weatherproofed for at-sea use (the external coating as supplied is water-resistant). The COTS target was designed to have a body temperature ten degrees Fahrenheit above ambient temperature (70° F.) and the head twenty degrees higher than ambient.

The prototype unit was initially powered by a 12VDC/22ah sealed lead-acid battery. The battery also served as ballast in a protective case below the target. Figure 1 shows the original GTT design.

Figure 1. An assembled GTT prototype is displayed.

2.2 Heated Diving Vest (HDV) Design

COTS technology provides for ocean-tested heated diving vests that operate in deep water under battery power (12vdc/10ah) for several hours. Used at the surface, the gel pads used to transfer the heat have a similar thermal signature to human skin, in a readily accessible design for purchase and modification to an "Oscar" design. Battery life for this design was 3.5- 4.0 hours at objective target temperature (88°-98°F) and up to eight hours above 70° F, target temperatures depending on atmospheric/environmental conditions. Figure 2 shows the HDV head unit viewed through the thermal infrared camera during testing. Average temperature values for each of the three position settings possible on the control knob are found in Appendix B.

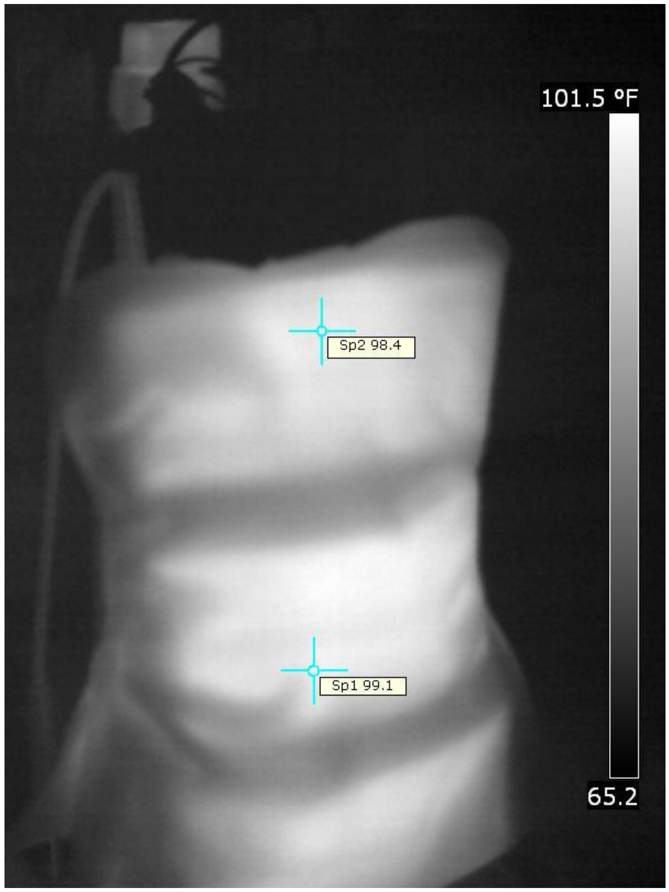

Figure 2. HDV prototype thermal testing is displayed, shown with the head unit only (front profile).

2.3 Test Equipment and Use

The primary tools for initial testing and IR measurement were a Raytek® infrared thermometer (with laser pointer) and a FLIR® Systems B400 hand held LWIR camera with 320x240 pixels infrared. The FLIR B400 also functions as a 1.3 megapixel visible spectrum imager. The camera was factory calibrated after purchase, and certified accurate within 3.6°F absolute, and sensitive to changes in temperature of 0.14° at 86° F. An external 76mm telephoto lens was purchased to aid in the field tests for distance imaging of thermal targets with the FLIR B400. Figure 3 shows lab testing of different designs, the video data from which was recorded using the FLIR B400 and analyzed. Appendix B-1 shows the equipment list for all the primary test equipment utilized throughout bench, developmental and operational testing.

Figure 3. Prototype testing is shown with the IR camera and video recorder.

2.4 Developmental Testing

Designs were bench tested for thermal comparisons to humans in the lab and then taken to a cool water temperature environment (pier side CG Station New London at dusk) and a warm water environment (an indoor heated pool at the CG Academy). Figure 4 shows a thermal infrared image with a human for comparison, with a HDV, GTT, and used GTT target (viewed from left to right, respectively).

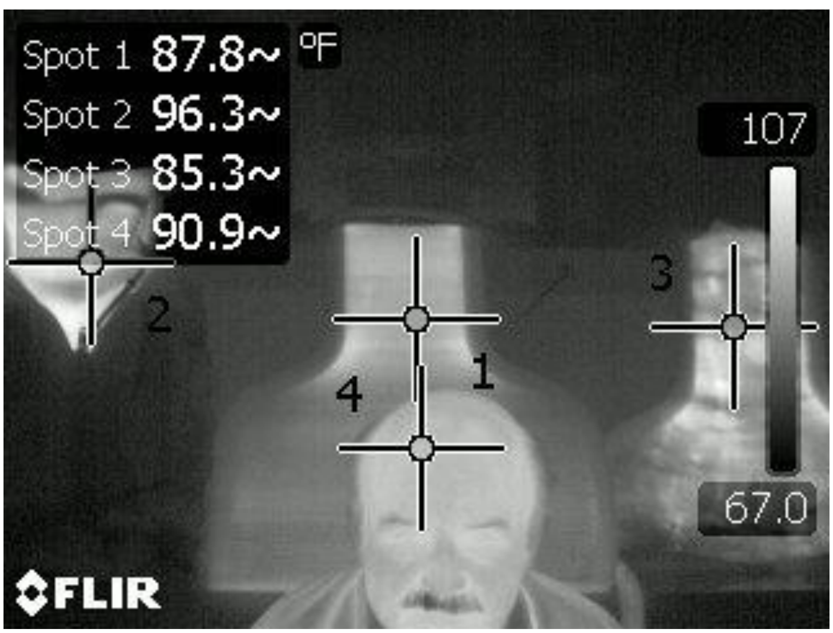

Figure 4. Bench testing comparisons of prototypes with a human.

2.4.1 Lab Testing

In-Lab testing focused on determination of current draw, temperature generation, and provided data on these metrics in varying environments for battery life and target durability (the GTT targets change their thermal signature after rough handling due to both breakings in the nichrome mesh used, and in emissivity changes based on the changes of the GTT "skin" (breakings of the external plastic coating, adding Velcro fasteners to the back of the target, etc).

Bench-testing of the GTT design found that the initial full-sized target generated temperatures from 88°-98°F, with a current draw of 5.2 amperes. Modifications included re-shaping the target to reduce current draw and increase target lifespan to support long, at-sea tests (approx 10 hours). The re-shaped target reduced current draw to 2.1 amperes, with temperature ranges of 91°-101° F at the visible head/shoulder area. Figure 5 shows a measurement of current draw on a modified GTT target. Average temperature ranges over time can be found in Appendix B.

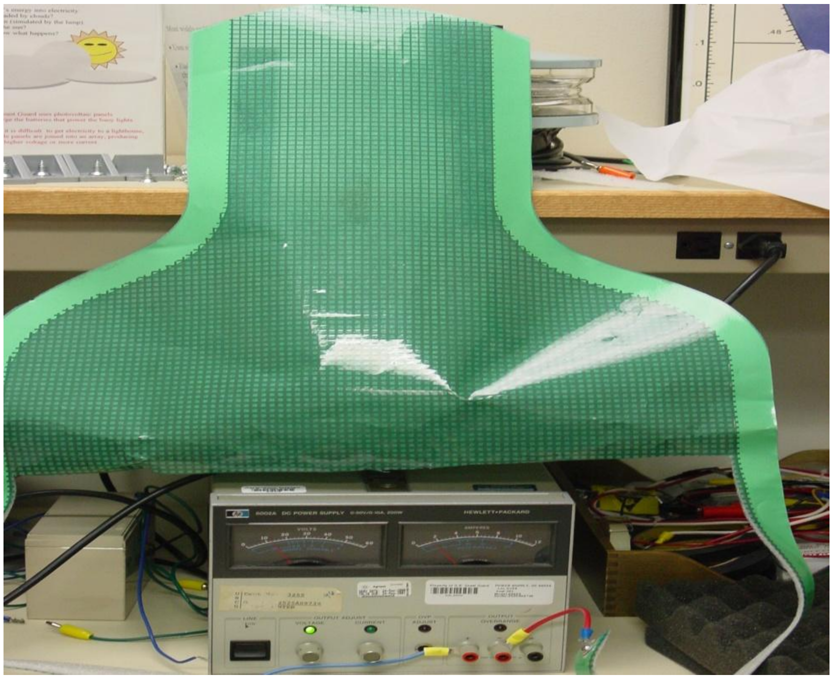

Figure 5. Bench power measurement is shown of a modified GTT target.

2.4.2 Shore/Pier Testing

Testing was originally conducted in the Thames River adjacent to the RDC. These tests evaluated the buoyancy of the unpowered targets, with ballast replacing batteries. Once a prototype of each variety (GTT and HDV) was verified operational (several different design variations of the GTT were made), evening tests at the same location were done to satisfy basic data collection, and to gauge ease of deployment and retrieval of the prototypes in more challenging environmental conditions. Figure 6 shows the initial test of the GTT design in the water.

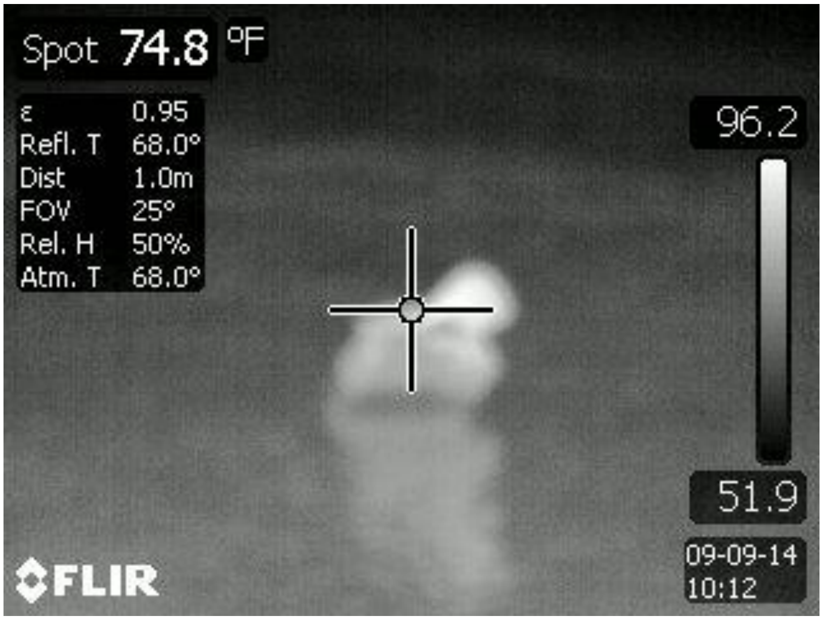

Figure 6. Initial thermal measurement is shown of a GTT Oscar in the water.

Testing then progressed to testing the prototypes pier side at CG Station New London, on the mornings of 22 and 23 September 2009. Surface water temperature was approximately 65°F. The atmospheric conditions were overcast and cool, and then became sunny and warmer, air temperature increased from 60° F to 75° F during the test period. Both designs showed good temperature accuracies to a human PIW initially, but both designs showed the effect of solar input, with target temperatures rising significantly after a few hours in the bright sunshine. Figure 7 shows a picture during initial daytime testing before the solar input became a factor.

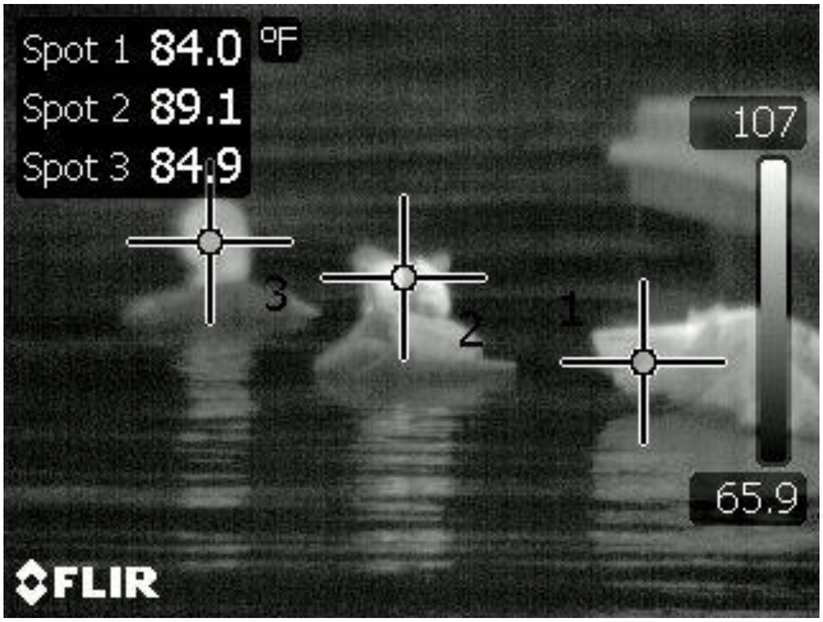

Figure 7. Daytime prototype testing is shown at the Thames River, pier side CG Station New London. From left to right, a human, a HDV Oscar, and a GTT Oscar are shown, with the HDV Oscar beginning to warm excessively due to solar input.

2.4.3 Pool Testing

Testing was conducted at the Coast Guard Academy Bullard Pool in the afternoon of 23 September 2009. A film crew supporting a presentation for the 2009 Innovation Expo was at both locations (pier side and the pool) on the 23rd, which provided a logistical test of the Oscars for movement and redeployment. Relocation was accomplished without the failure of a prototype. The indoor air temperature was 86° F., and surface water temperature was measured at 82° F. Temperature comparison with a human PIW went extremely well in this environment. Continued use and rough deployment techniques (the prototypes were thrown into the water, to simulate deployment from a high-decked platform, and were dunked repeatedly to measure temperature variations and recovery times) caused the prototypes to lose the buoyancy perspective of a PIW, usually lying horizontal on the water unless held at the proper position by the human. More work was needed to ensure the ruggedness of the ballast housing, and the body of the prototypes, in general. Battery life was approximately 4 hours of usage time for the HDV design, the GTT targets worked at desired temperatures throughout the test. Figure eight shows side by side a human in the water with the Thermal Oscars in the visible and thermal infrared spectrum.

On 28 September another round of pool testing was completed, with the pool unheated (surface water temperature 72° F., air temp 80° F.) Results were similar to the 23rd, with a change in image based on the surface water temperature.

Conclusions from these tests determined that a frame needed to be built that could support the external shape of the prototype(s), in order to hold ballast for proper target perspective and to aid in transport by means of the frame. Figure 8 shows a visible and thermal infrared image comparing a human swimmer with a GTT and HDV Oscar from the pool test.

A GTT design Thermal Oscar was displayed at the Coast Guard Innovation Expo, October 2009.

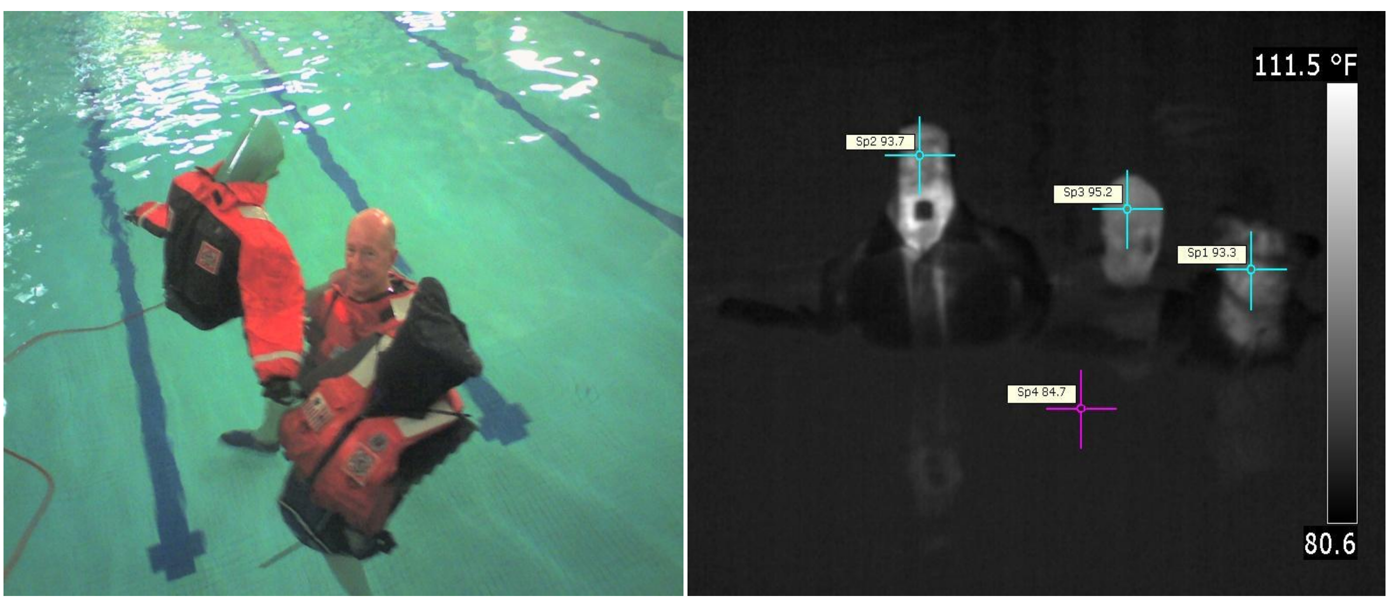

Figure 8. Testing is shown at the USCG Academy pool (Heated), of a human and Thermal Oscars in the visible and thermal infrared spectrum. Temperature difference is within two degrees Fahrenheit.

2.4.4 Post Testing Modifications and Evaluation

Both Oscar designs were encased in PVC frames for increased ruggedness and ease of transport/retrieval. On May 10, 2010, buoyancy tests were completed in New London with the new frames satisfactory; using variable amounts of ballast until proper buoyancy was achieved. On May 14, 2010, the new designs were tested satisfactory for operational use, based on evaluation of deployment and retrieval of the Thermal Oscars without need of repair and their proper perspective to the waterline, which was similar to that of a human PIW with head and upper shoulders above the waterline. Figure 9 shows buoyancy testing of two GTT designs, with the design on the left showing superior perspective in the water to the design on the right.

Figure 9. Comparison testing of ruggedized GTT Oscar designs, Thames River.

2.5 Operational Testing

Operational testing was performed approximately 7nmi offshore Clearwater Beach, FL, with the USCGC THETIS (WMEC 910) as the test platform using the Shipboard Infrared Video Sensor System, and the RDC's calibrated IR camera.

2.5.1 Objectives

The objective of the Test Plan was to acquire video and still images of the Thermal Oscars with two Coast Guard AST rescue swimmers who were to alternate between a staged raft and the water. The swimmers wore Personal Floatation Devices (PFDs) and a float was staged for their use while in the water. Testing was conducted on the nights of 21-22 June.

2.5.2 Test Parameters

Safety considerations placed the targets (one HDV and one GTT) about 100 yards from the human swimmers. This distance was within the field of view of the WMECs SIRVSS, to capture both the humans and the Thermal Oscars in a single image. The handheld camera was used from the cutter's Over-the-Horizon (OTH) rigid hull inflatable boat (RHIB) that served as the safety boat for the swimmers. The distance between the human swimmers and the Thermal Oscars made it so the handheld camera could capture either the swimmers or the Thermal Oscars, but not both. Surface water temperature was measured by a FLUKE® digital thermometer with probe, and compared to the FLIR B400's measurements for accuracy. The OTH boat delivered the Thermal Oscars and the swimmers to the site, and the cutter backed off from the site out of sensor range, then approached along the search path as determined in the test plan.

Night SIRVSS tests centered on detection of both occupied and unoccupied life rafts and PIWs, using the Medium Wave Infrared (MWIR) capability of the SIRVSS. Life rafts, the safety boat, and the WMEC were equipped with GPS data recorders for this test. This test employed a modified single-unit sector "search" pattern, at a speed of approximately 6 knots, as depicted in Figure 10. The circular red symbols marked U, O, or PIW indicate the notional positions of Unoccupied, Occupied, and PIW safety boats, respectively. All were placed 0.1 nmi away from the search pattern datum (nominally 27° 33' N, 80° 07' W), and between planned search legs. This provided approximately 100-yd minimum separation of the targets from the WMEC's planned search legs. The unoccupied life raft was equipped with a radar reflector to allow its detection by radar and avoidance by the WMEC. Swimmers were placed in the water as the WMEC turned inbound or closed to 1.5 nmi from the datum. Data was collected by both paper log (noting sensor settings, detection time, laser range, and sensor acquisition), and video recording of the sensor image for post-test analysis (unfortunately, the video recording was not saved). Two nights of IR data collection were conducted.

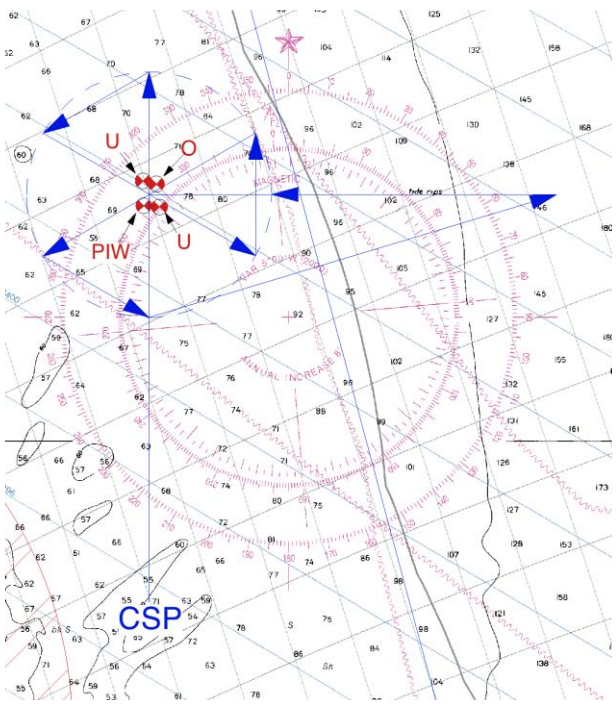

Figure 10. Modified Sector search pattern employed for the test.

2.5.3 Operational Testing

R&DC members were onboard the WMEC for the testing, to monitor the SIRVSS system, while an R&DC member embarked on the OTH boat with the FLIR B400 handheld and temperature probe. The original plan called for the handheld camera and video recording equipment to be on a USCG Auxiliary vessel, but the plan was modified due to weather and safety considerations (Thunderstorms cancelled the first scheduled night test on 20 June, as the auxiliary boat was unable to embark).

On the night of 21 June, swimmers were deployed at 2100, with the Thermal Oscars deployed shortly thereafter. Air temperature was 88°F, water temperature 86.5°F, creating a challenging environment for testing due to the low difference in measurable temperature between the background and the Thermal Oscars or human swimmers. Seas were approximately 3 feet, with winds of 9-11 knots, and made use of the handheld camera extremely difficult due to focusing limitations in the sea state. Sea state and an incoming thunderstorm (with lightning) cancelled the test at about 2230. Figures 11 and 12 are thermal infrared images of the GTT and HDV Thermal Oscars, shortly after the Oscars were deployed.

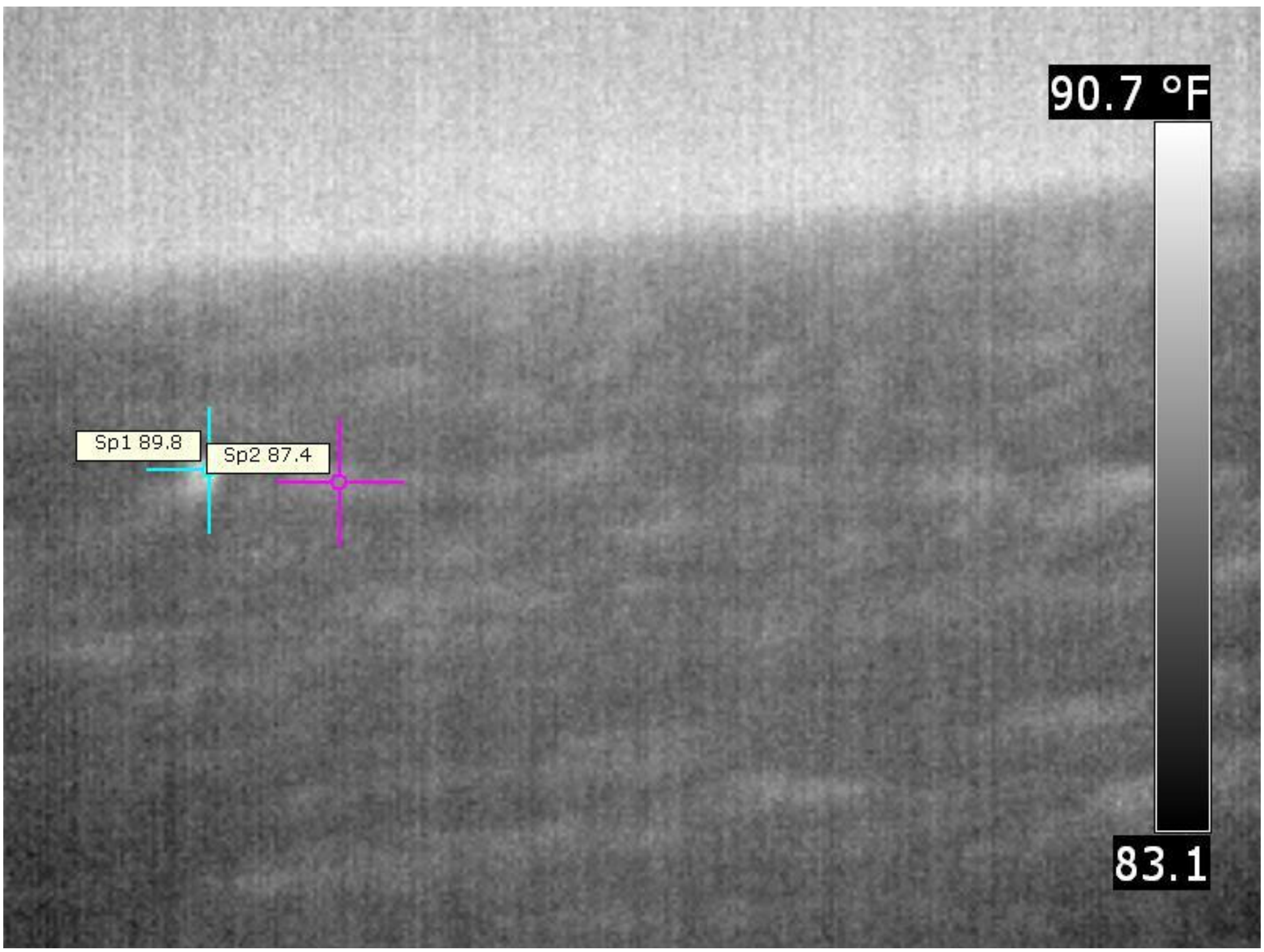

Figure 11. Thermal infrared image of the GTT Oscar is shown from the first night of testing. The temperature difference was 2.4 degrees Fahrenheit between the GTT Oscar and the maximum sea water temperature created from thermal clutter due to whitecaps.

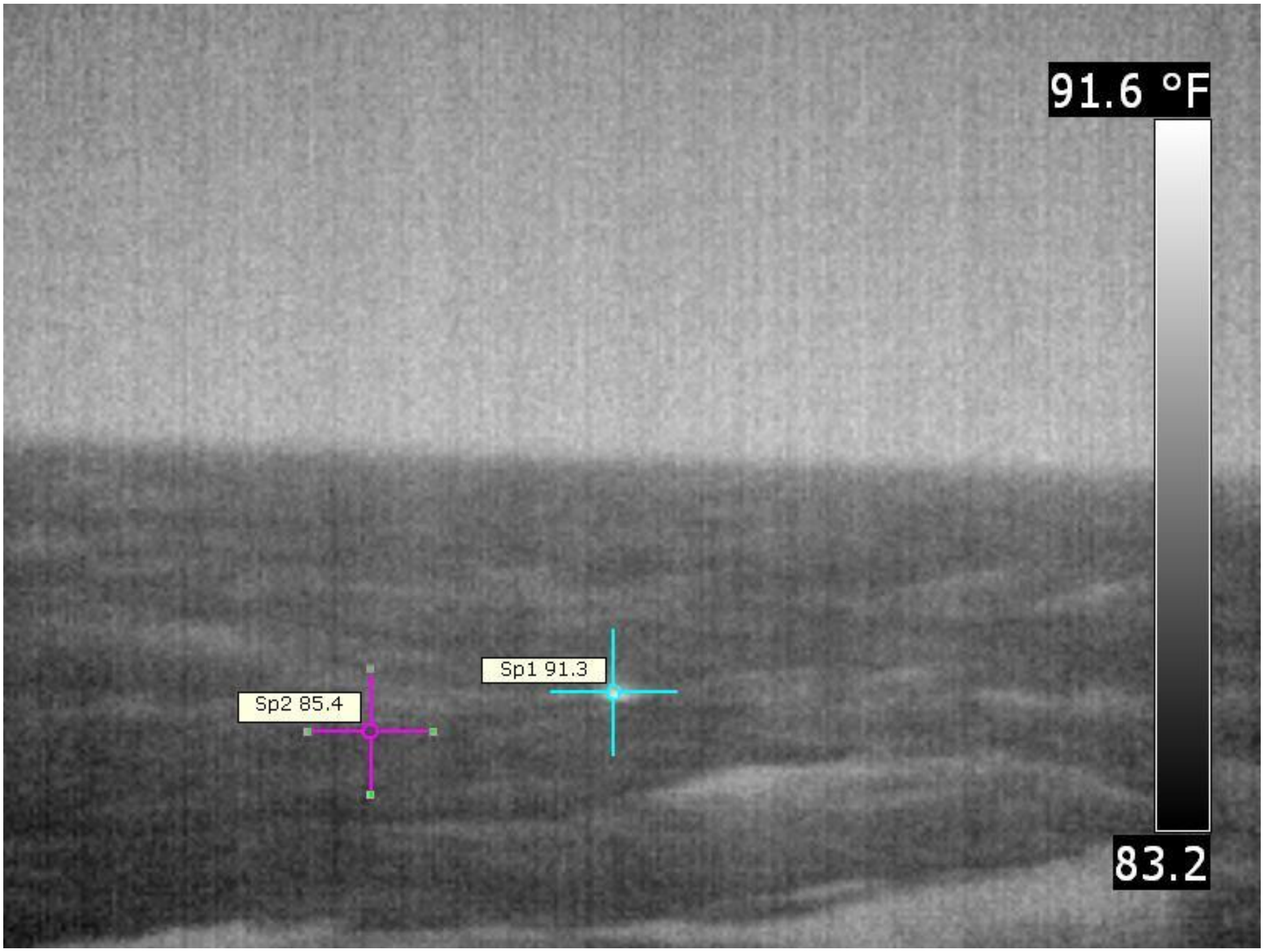

Figure 12. A thermal infrared image is shown of the HDV Oscar on the first night of testing. The cursors display a six degree difference between the Oscar and the water.

The WMEC reported difficulty in seeing the Thermal Oscars. A determination was made between RDC research personnel to modify the HDV design with a clear, thin plastic bag around the head unit in an effort to retain heat and lessen effects of water saturation from waves and rain. Figure 13 shows a swimmer in the raft prior to test cancellation, with measured temperature about six degrees Fahrenheit above the ocean temperature.

The transfer of the targets from the WMEC to the OTH boat, and the return of the targets from the OTH boat to the WMEC caused the targets to be handled by crew members unfamiliar with any aspect of the targets. The combination of the physical difficulty of the transfer and personnel inexperience with the targets caused physical damage to both target types, primarily from improper handling (holding/grabbing the Oscars from vulnerable spots normally not used for weight-bearing during use or transport).

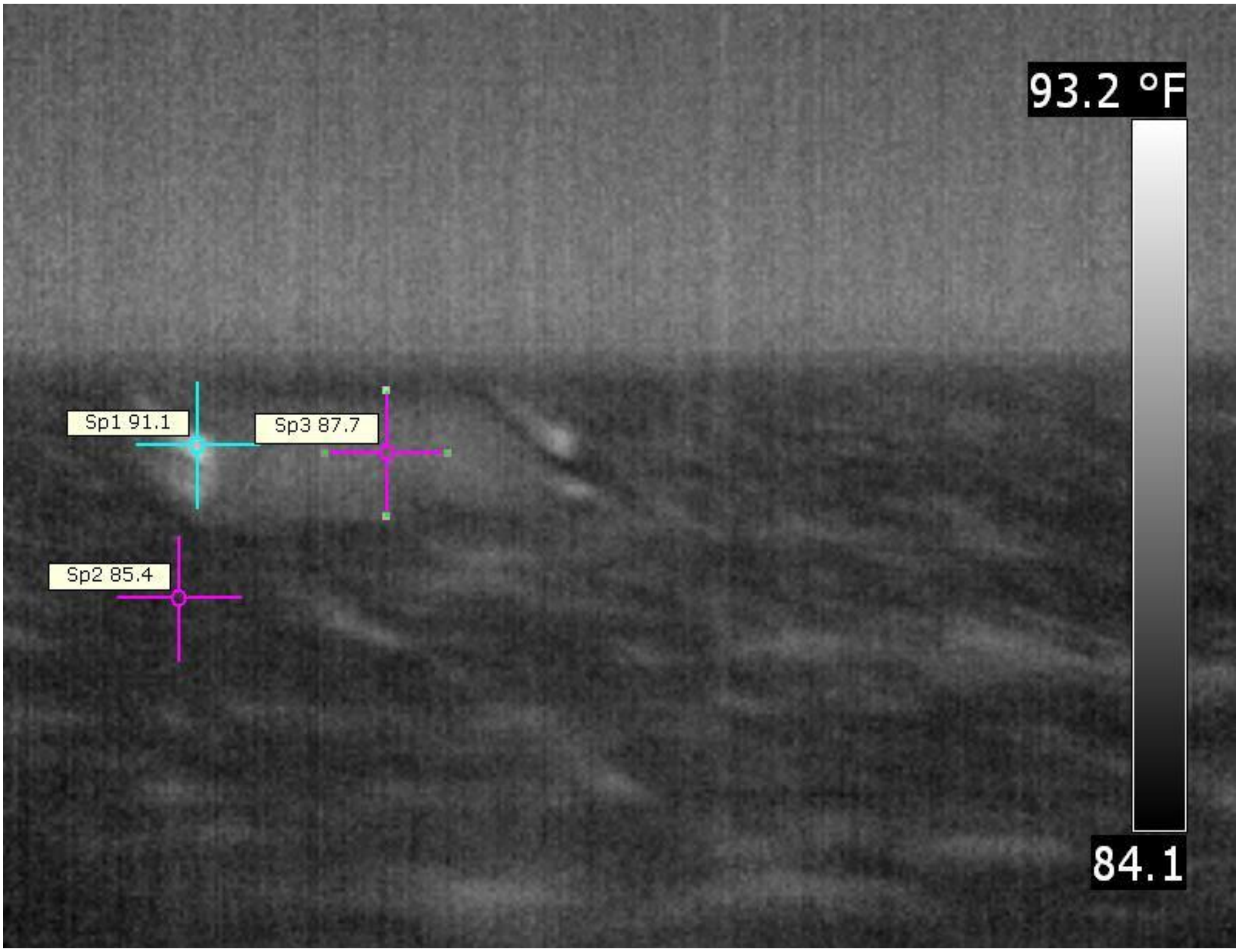

Figure 13. Thermal infrared image is shown of a human in the raft during the first night of testing. Temperature difference was 5.7 degrees Fahrenheit.

The GTT OSCAR suffered damage to the target and frame during transfer from the OTH boat back to the cutter. Repairs to the GTT OSCAR were quickly made upon return to Station Sand Key the following morning, and its battery recharged; while the HDV OSCAR only needed battery recharge and frame maintenance. Figure 14 shows the repaired target compared to a human at CG Station Sand Key.

Figure 14. GTT OSCAR target repair testing compared with a human, CG Station Sand Key.

The second night of testing commenced at 0300. Conditions were cooler several hours after sunset (compared to the first night of testing, which started shortly after sunset), as air temperature was 82°F, and surface water temperature was 78.5°F. Winds were approximately 15 knots, and seas were approximately 3-4 feet. These weather conditions created significant whitecaps, as shown in the photos. The whitecaps created thermal clutter on the ocean surface, on average four degrees Fahrenheit above the ambient ocean surface temperature. Figure 15 shows the GTT Oscar, upon initial deployment on night two of the test.

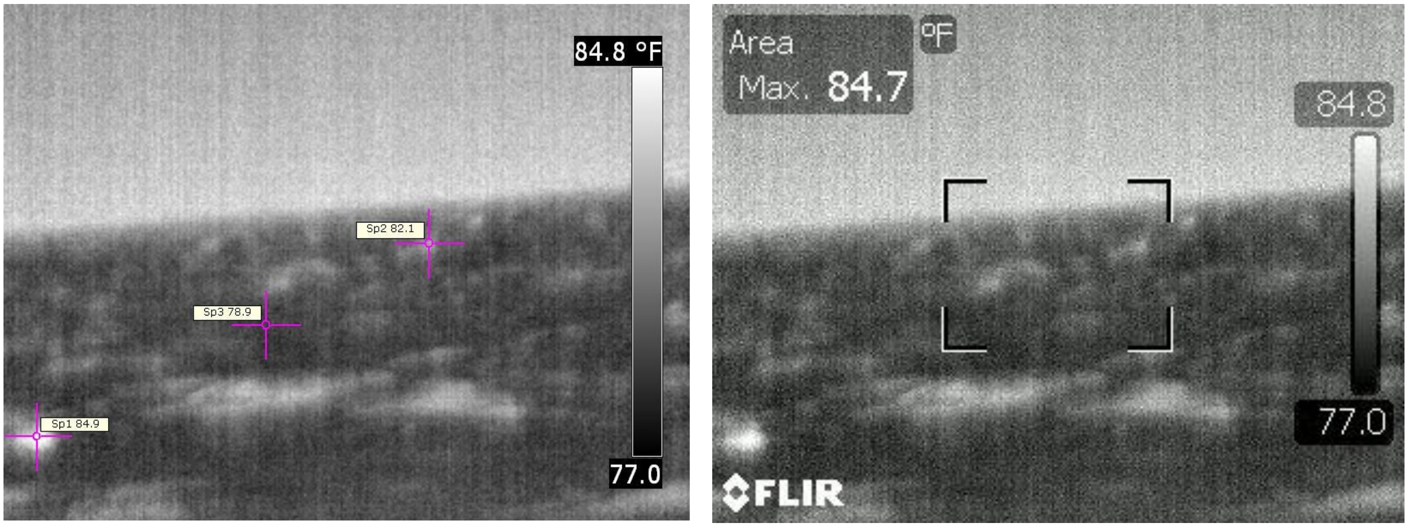

Figure 15. Thermal image of GTT OSCAR (lower left crosshair), compared to minimum and maximum sea water temperatures, shown with and without temperature cursors. The difference in temperature between the Oscar and the non-whitecap ocean temperature was six degrees Fahrenheit.

Observations/recommendations on the cutter were favorable towards the HDV Oscar, from anecdotal evidence provided by the research team and WMEC crew. Figure 16 shows an image from the handheld taken of the HDV Oscar, displayed with and without temperature cursors. Sea temperature was cooler in the middle of the night for night two, allowing for easier acquisition and observation due to a higher difference in temperature between the ocean surface and the Oscars and PIWs.

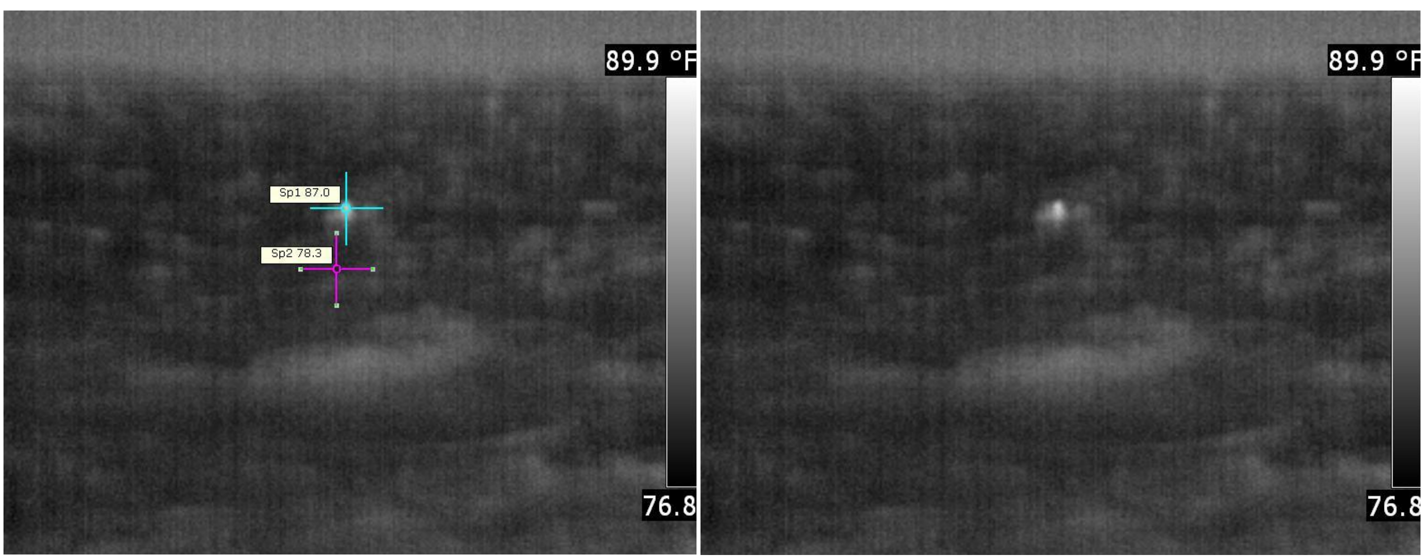

Figure 16. Thermal Infrared Image of HDV OSCAR (shown with and without cursors); taken at 0345on the morning of 23 June. Difference in temperature between the Oscar and the non-whitecap ocean temperature was nine degrees Fahrenheit.

Although the sea state and range from the OTH boat to the targets made the handheld insufficient for quality photos, figure 17 shows both swimmers, one in the raft, and the other holding onto a buoy tethered to the raft. The pictures of the Oscar and the humans were taken fifteen minutes apart.

The WMEC logs showed detection ranges of the Oscar and PIW's as follows:

Thermal Oscar or PIW detection ranges were from 837 – 1415 yards, using an Infrared Standard ("white hot") display on the SIRVSS. The average detection of targets was about 1100 yards at the system's maximum magnification.

Anecdotal evidence from RDC staff, WMEC personnel, and test personnel found the Thermal Oscars looking "identical" to the PIWs in maximum zoom, "white-hot" display use. Video or still picture imagery from the WMEC during the testing is unavailable.

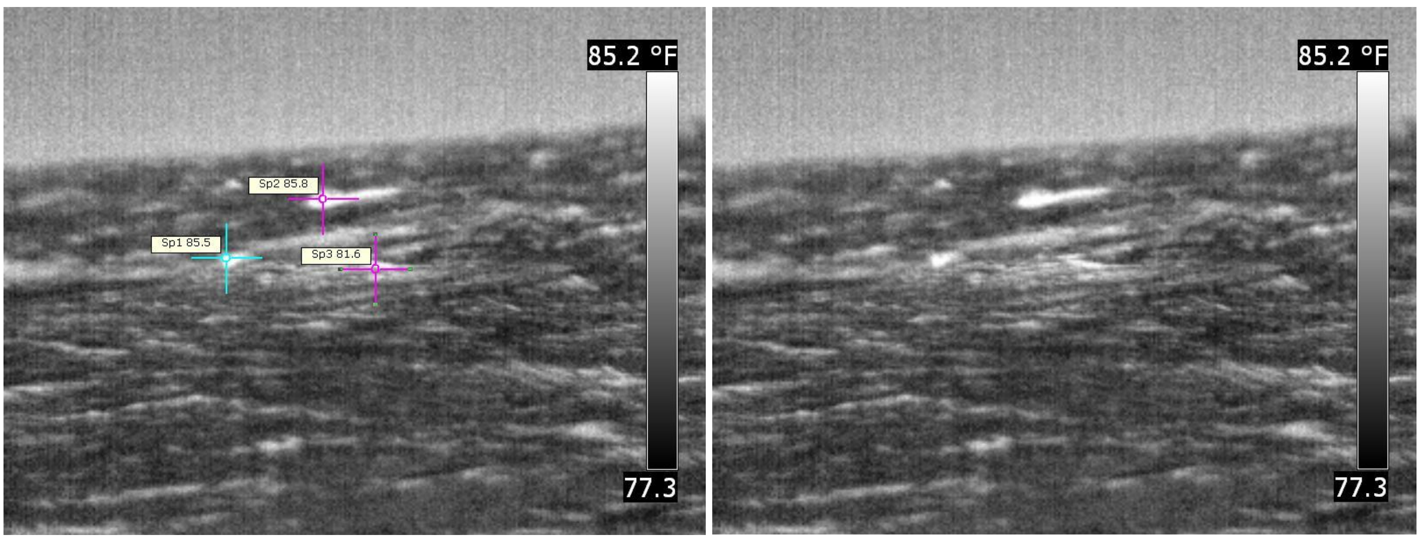

Figure 17. Thermal infrared images of human PIWs in the water and in the raft, 0400. (Image shown with and without temperature cursors). The human PIW in the water (blue cursor) is holding onto a float attached to the raft. Difference in temperature between human in the water and non-whitecap ocean temperature was 8.6 degrees Fahrenheit, and four degrees above the whitecap ocean temperature shown at right in the image.

3 CONCLUSIONS

The HDV Design gives 3.0-3.5 hours of human-equivalent temperature at sea; it is simple to build, inexpensive (approximately $1200), is a durable design that is environmentally safe in an ocean environment, and is capable of rapid deployment and retrieval. For an additional $700 a second battery unit could be purchased and wired together (some modifications would be necessary) to prolong operational life by an additional 3-4 hours. The HDV target provides a near-equivalent thermal cross-section to a human PIW, for both ship borne or airborne testing. The HDV design is vulnerable to solar absorption during the daytime, and to adverse surface cooling induced by environmental (wind/rain/high seas) conditions. The latter effect is significantly reduced by placing a plastic bag around the HDV head unit, which collects the heat inside the bag, reducing wind and rain effects considerably. The PVC frame required constant minor maintenance.

The GTT Design gives up to 12 hours of Human-equivalent temperature at sea. It is relatively simple to build, very inexpensive (approximately $300), not extremely durable, and could be a hazard in an ocean environment (lead-acid battery). The GTT is ideally suited for a raft, and usable as a PIW in calm conditions, with controlled deployment and retrieval. The GTT design does not provide a uniform target, due to the target shape, but this limitation would be negligible in a raft environment. Using multiple targets and increased waterproofing methods for the battery could make for an acceptable GTT PIW, but there is no need to do so at this time, with the HDV being within performance and cost thresholds. Figure 18 shows the effect of repeated use on the GTT target's thermal infrared signature.

Figure 18. GTT target comparison- new and post-test (Note non-uniformity of the Post Test Target due to damaged wire mesh).

4 RECOMMENDATIONS

Based on the rigorous, at-sea operational testing with a USCG unit, the HDV target is a more reliable solution for PIW IR testing and training. The GTT target is an acceptable solution for raft testing, given the physical protection of the raft. The long life of the GTT allows it to be staged several hours prior to a test. These targets have value as coarse equivalents of human PIW s for IR search and detection training, but are not human equivalents for hypothermic studies or precise analysis. The PVC frames, while functional, are difficult to reproduce to exact specifications, and involve environmental issues with using PVC cement. The PVC frames are recommended to be abandoned for a plastic square-frame design described in Appendix A, which has the same buoyancy perspective as the PVC frame. Figure 19 shows a side-by-side picture during pool testing that is the best representative photo of comparing the HDV Oscar design to a human PIW in respect of size, perspective, and thermal signature.

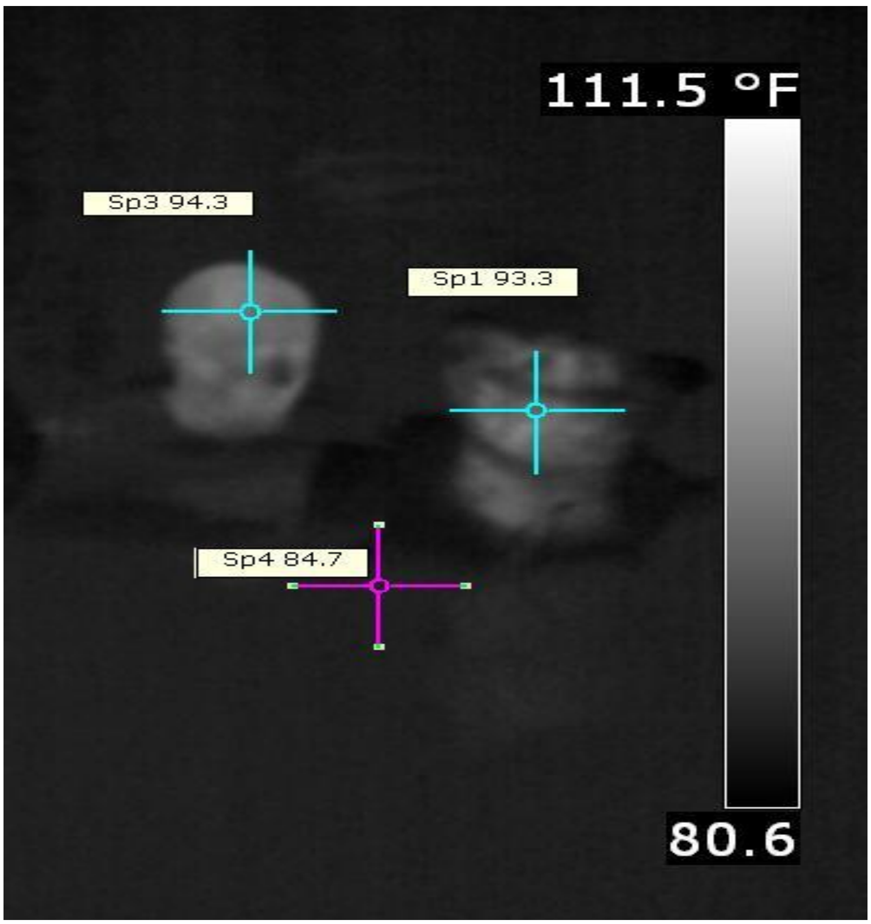

Figure 19. Human PIW is shown with the HDV design Thermal Oscar at CG Academy pool. Temperature difference is one degree Fahrenheit, between the human and the Oscar, at about ten degrees Fahrenheit above surface water temperature.

5 REFERENCE LIST

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APPENDIX A. PROTOTYPE DESIGNS PARTS LIST AND ASSEMBLY INSTRUCTIONS

A.1 GTT OSCAR

The raft design is made to work with the infantry target wrapped around a base to create a proper thermal cross-section. The flat battery case serves to stabilize design on a raft, great care must be taken if attempting to use this design for at-sea testing, due to the danger of salt water contacting the battery terminals (either in a raft or PIW design). Table A-1 shows the GTT Oscar parts list, and table A-2 the tools required for construction.

A.1.1 GTT OSCAR Parts List

Table A-1. GTT OSCAR parts and price list.

Gradient Thermal Infantry Target Design (GTT)	**Location**	**Price**
Thermal Target- Tech Valley Technologies	http://www.techvalleytech.com/Thermal.html	67.00 USD
Battery (Sea-Gel Battery Group U-1), 12vdc, 31ah	West Marine	140.00 USD
Battery Case (U-1)	West Marine	40.00
Personal Flotation Device (PFD)	West Marine or local	Acquire
Plastic cable gland with attaching hardware/fittings for a one-half inch inner diameter pipe.	Local or Home Depot or www.usplastic.com HINCO® Part # MS 16170-18, size 4T.	20.00 USD
Pipe, flexible air conditioning, 12”, 1/2” inner diameter, ¾ “outer diameter.	Local or Home Depot or www.usplastic.com	5.00 USD
Orange road vest or equivalent	Local or Home Depot	Acquire
Head Assembly (small float or equivalent- round 10”.	West Marine or Local	Acquire
Marine-grade Room Temperature Vulcanizing (RTV) silicone, or similar substance	West Marine or Local	10.00 USD
Fastening Material (Tie straps, silicone tape, Velcro)	West Marine or Local	Acquire
Two (2) 90° PVC fittings, for ½”pipe	Local or Home Depot	5.00 USD
TOTAL PRICE	**290.00 USD**	

A.1.2 GTT OSCAR Tools List

Table A-2. GTT OSCAR tools list.

Standard Drill	Battery Powered preferred, locally obtained.
1 ¼ inch Hole Saw bit and attachment	Locally obtained
Single-Hole punch	Locally obtained
Diagonal Cutting Pliers	Locally obtained
Safety Goggles	Locally obtained
Safety Gloves	Locally obtained

A.1.3 GTT OSCAR Assembly Instructions

Instructions are given with post op-test improvements that are dedicated for raft use.

Gradient Thermal Target Prototype Design (RAFT):

1) Place the battery in the case, as shown in Figure A-1.

Figure A-1. GTT OSCAR battery case.

2) Drill a 1- 3/4” hole in center of the battery case cover (a hole saw attachment is recommended). Use the gland nut assembly to make a watertight connection on the cover, use the marine RTV to fill any openings between the stuffing tube connections and the cover. Figure A-2 shows a sequential step through of assembling the watertight gland nut; use the watertight RTV (if desired) to seal the connectors after satisfied of a properly made hole and connection. Figure A-3 shows the gland nut/stuffing tube physical relationship (The battery cover hole being the location of the gland bolt, and the parts shown in order of assembly, for a further explanation of the assembly.
3) Thread the flexible air conditioning pipe through the gland nut, with about ten inches of the pipe showing above the battery cover as shown in the lower right picture of figure A-2.

4) Cut out a round 1 ½" hole in the lower-center of the Target body. - The hole allows for the target to go around the flexible pipe that will come from the front-center of the battery case cover.
5) Thread the float onto the flexible pipe, resting on top of the battery cover.
6) Thread the 90° PVC connections on the top and bottom of the pipe. Install the GTT/Head assembly above the battery cover, by wrapping it around the float. Use the single-hole punch to make connection holes to attach target to itself (for shape) with tie-straps, as shown in Figure A-4, middle figure.
7) The leads from the target are placed inside the flexible pipe, and to the battery terminals.
8) Enclose with vest (or PFD), if desired, as shown in Figure A-4.

Figure A-2. The flexible pipe construction onto the battery cover is depicted.

Figure A-3. The cover is shown with an exploded view of a gland nut seal, showing the proper order and location of the gland nut parts.

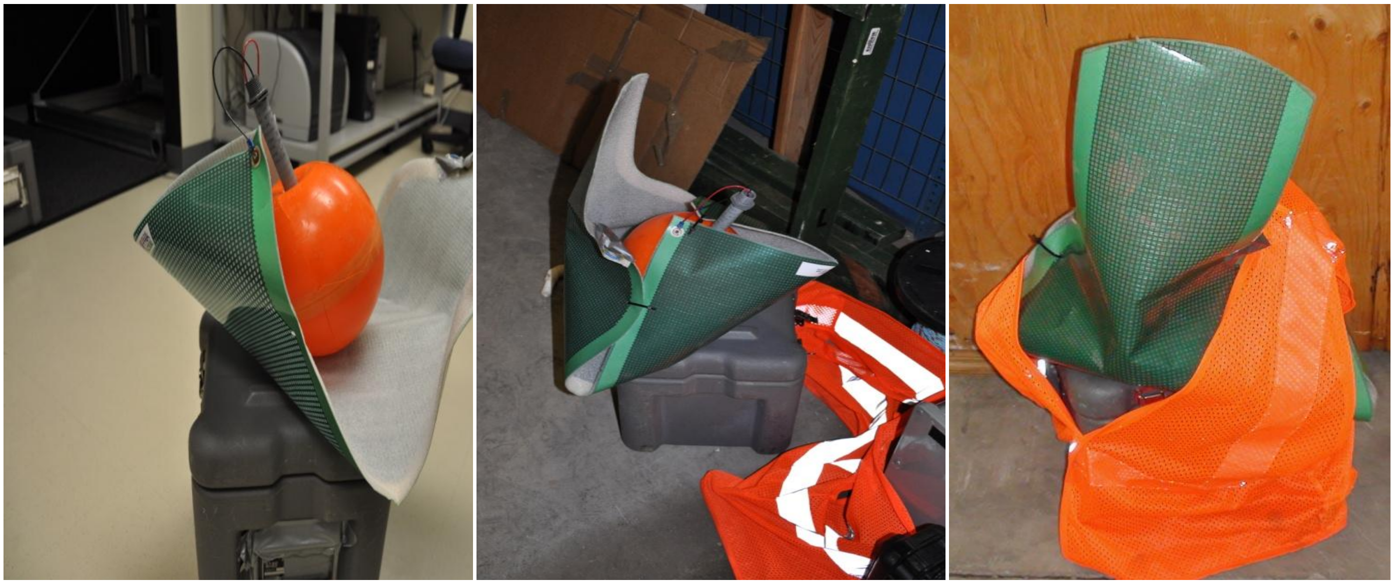

Figure A-4. The GTT and float are shown on top of battery case, the completed head unit is shown, and a completed GTT Oscar.

A.1.4 GTT OSCAR Operation

Prior to use, open the case, and connect the wires from the target to the battery, arrangement shown in figure A-5. Close the case, test to ensure heat is emanating from the target, and place into the raft when ready (The target should run for over 12 hours, so there is plenty of time).

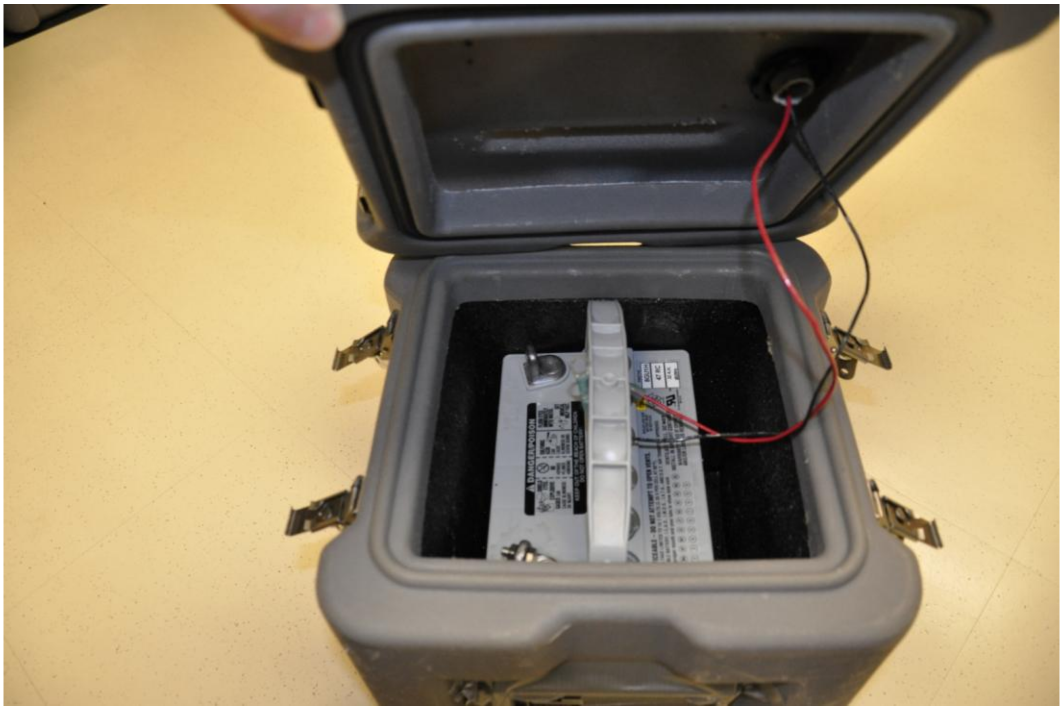

Figure A-5. Open battery case, showing GTT leads and the gel-cell battery with terminals for wire installation.

A.2 HDV OSCAR

The PIW-recommended HDV design works readily at sea without any separate ballast units. Improved post op-test design utilizes plastic crate vice a PVC frame for expedience in construction and labor cost. These advantages come without the loss of physical integrity or buoyancy perspective. The design places the OSCAR head just above the waterline. The current parts list is for the HDV OSCAR; as depicted below in Table A-3. The tools required are shown in Table A-4.

A.2.1 HDV OSCAR Parts List

Table A-3. HDV OSCAR parts and price list.

Heated Diving Vest Design (HDV)		
Heated Diving Vest	Q-Vest Drysuit heating system (Extra-large) Available at www.golemgear.com and other diving sites.	950.00 USD (Extra Battery is additional 650.00 USD)
Insulated Bag (Battery Case)	Battery is self-contained and waterproof.	20-100 USD
Plastic crate	Plastic Crate (Sterilite® or equivalent, 14.25”x9.5”x10.6”) Available at Wal-Mart® and similar stores.	4.00 USD
Plastic Head Assembly	Jar, 8 inches high with 6 inch diameter.	Acquire
Personal Flotation Device (PFD)	Type III USCG approved or equivalent	Acquire
Attaching Hardware	Tie-straps, Velcro, Silicone Tape	Acquire
Ballast (2) 8-lb dumbbells.	Inside Bag Unit	20.00 USD
Ballast (1) 2.5 lb barbell weight.	Inside Head Unit	5.00 USD
Polyvinyl Chloride (PVC) pipe	2 feet, ¼” diameter, of conduit or higher quality	6.00 USD.
Total Price	**1005.00 USD (single battery)= 3.5 Hours PIW Equivalent**	**1655.00 USD (two batteries) = 7 Hours PIW Equivalent**

A.2.2 HDV OSCAR Tools List

Table A-4. HDV OSCAR tools list.

Standard Drill	Battery Powered preferred, locally obtained.
1 ¼ inch Hole Saw bit and attachment	Locally obtained
Diagonal Cutting Pliers	Locally obtained
Safety Goggles	Locally obtained

A.2.3 HDV OSCAR Assembly Instructions

Figure A-6 shows all the parts necessary for HDV Oscar construction.

Figure A-6. The HDV Oscar components are displayed.

1) Remove the lid from the jar, and Velcro the 2.5 lb weight to the inside of the lid. Place the lid on the jar and position so the lid is on the bottom (jar is upside-down), as shown in figure A-6.
2) Wrap the Q-Vest around the Head assembly, as shown in figure A-7. Use Tie-straps and/or Silicone Tape to hold the vest wrapped to the jar.

Figure A-7. The heated diving vest is shown prior to securing around the jar. (Note-this makes the head unit).

3) Place the Battery Case and ballast (16 lbs.) in the Bag, to ensure proper fit, then remove. Figure A-8 shows the arrangement inside the bag.

Figure A-8. The battery and ballast arrangement is shown inside the bag.

4) Drill ¼” holes into the front, rear, and sides of the crate, as shown in Figure A-9. Use 8ft of polypropylene rope, and place each end through the side holes and secure.

Figure A-9. Drill hole is shown in the crate, in the middle of the crate.

5) Place the PVC pipe into the back of the crate (centered), and attach with tie straps through the holes in the crate. Next, place the bag into the crate. Figure A-10 shows the pipe attached in the crate, (with a single strap for illustration) and with the bag inside the crate.

Figure A-10. PVC pipe installed in crate, and with the bag unit inside the crate.

6) Enclose the crate with the PFD; attach the two with tie-straps using crate holes and PFD rings, using the upper and lower portion of the PFD to ensure stability. Figure A-11 shows the PFD around the crate, and Figure A-12 shows one of the upper forward tie-strap locations.

Figure A-11. The PFD, crate, and bag are shown before connecting (the pipe was removed for illustrative purposes).

Figure A-12. An upper-forward tie-strap connection of the PFD is made to the crate.

7) Ensure that the head unit is properly secured, with the vest fully around the jar. The shoulder straps of the vest are to be located just below the lid of the jar so they can be used in step 9 to connect the head unit to the PFD. Figure A-13 shows the head unit from a front, rear, and side profile. Orange silicone tape is recommended for visual assistance, tie-straps can be used for initial and/or additional support.

Figure A-13. Front, rear, and side views of the HDV head unit.

8) Place the head unit on the pipe, slide in-between the jar and the vest. Figure A-14 shows the pipe inside the head unit for illustrative purposes, the pipe would normally be attached to the crate.

Figure A-14. PVC pipe is shown inserted into the head unit.

9) Attach the shoulder straps (at the bottom) of the vest to the shoulders of the PFD with tie-straps, the completed picture should look like figure A-15.

Figure A-15. HDV with head unit connected to the pipe and the PFD.

10) Figure A-16 shows the completed item. Attach a chem-lite to the rope for added visibility. Use a second length of rope and attach through the front and rear holes for additional stability in retrieval, if desired.


Figure A-16. Pictures of completed HDV Oscar.

A.2.4 HDV OSCAR Operation

1) Prior to exposure to wet conditions, connect the battery case cable to the Q-Vest cable as shown in figure A-17. Ensure slack exists in the cable after the connection between the battery and the Q-Vest is made, and wrap the connection with a small amount of silicone tape for additional protection from the environment (recommended). Store cable slack inside the bag.

Figure A-17. Connection of the power cable is shown (in progress) between the battery and the Q-Vest.

2) Controls: The heating control knob is off in the fully counter-clockwise position. One turn to clockwise is the recommended (lowest) setting, for maximum life and realistic temperature. Place the knob clockwise two positions for the middle setting giving higher temperature and shorter life (for cold water or initial training simulation). The highest (fully clockwise) setting is not recommended, as the temperature is too high and the lifespan is very short, but it could be used similarly to the middle position. Figure A-18 shows the control knob in the "off" position. Turn on the power knob to the desired setting when ready, and then place the HDV Oscar in the water.

Figure A-18. The battery case control knob, shown in the "off" position. Note: battery is shown while charging, with the red cable plug in the charging port (normally capped).

A.3 Dry Bag Use (Optional)

Post Op-test testing found that a dry-bag with a backpack design was optimal for battery protection and retrieval. The dry bag can be used either with a PVC frame or the crate design for ease of manufacture. Additional ballast should be used with the HDV design to compensate for the air inside of the dry bag. Figure A-19 shows a prototype dry bag with PVC frame design.

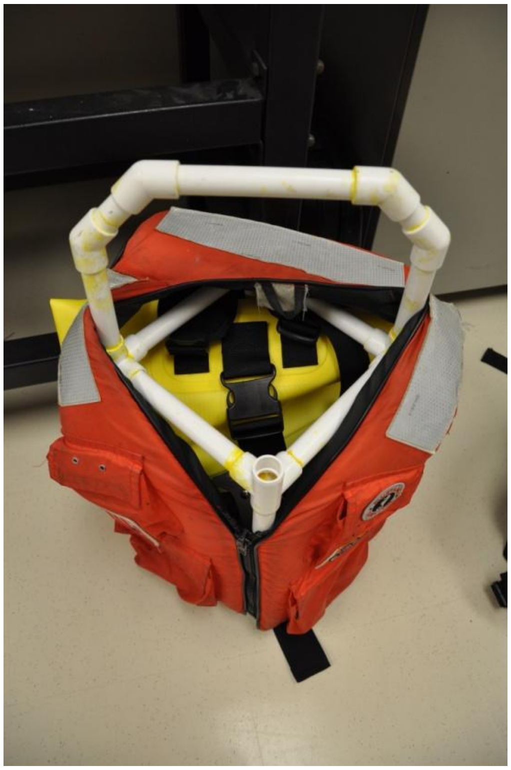

Figure A-19. Dry bag in PVC frame.

All of the designs shown are guidelines for building inexpensive, coarse thermal targets for testing and drills. All designs incorporate buoyancy testing (use of ballast) for optimum placement of the heated target just above the waterline, similar to a human PIW. Contact the R&DC if desiring to construct PVC frames, advice on design modifications, for individualized recommendations and for lessons learned.

APPENDIX B. PROTOTYPE DESIGN(S) INITIAL TEST DATA

B.1 Primary Test Equipment

Table B-1. Test equipment list.

ITEM	DESCRIPTION	PRICE
FLIR® B400 LWIR Infrared Camera	1.3 Megapixel visible spectrum mode, 320x240 pixel IR resolution, 25°x 19° lens standard with an IFOV of 1.36 mRad.	17,000.00 USD
FLIR® Telephoto lens.	76mm, 6°x 4.5° lens	7,000.00 USD
RAYTEK® ST3 Digital Laser Infrared Thermometer	Temperature range 32 to 750°F.	75.00 USD (equivalent model)
SONY® GV-D1000 portable Mini DV video recorder		1000.00 USD
FLUKE ® 51 II Digital Thermometer with Probe	Accurate +/- 0.5°F above zero degrees in normal operating temperatures.	225.00 USD
FLUKE ® 87 III True RMS Digital Multimeter		200.00 USD
Hewitt Packard 6002A DC Power Supply	Range: 0-50 VDC, 0-10 Amperes.	450.00 USD

B.2 HDV OSCAR Test Data

Table B-2. HDV temperature testing (lab).

Temperature	Pos 1		Pos 2		Pos 3	
	F°	**ΔT(degrees Fahrenheit)**	**F°**	**ΔT(degrees Fahrenheit)**	**F°**	**ΔT(degrees Fahrenheit)**
0900	74.8	0	73.6	0	74.6	0
0915	87.4	14.1	89.1	15.5	109.1	34.5
0930	95.4	6.5	100.4	11.3	130.7	20.4
0945	98.3	2.9	107.4	7.0	133.8	3.1
1000	99.2	0.9	108.1	0.7	127.4	-6.4
1015	99.4	0.2	108.1	0.0	125.3	-2.1
1030	99.3	-0.1	107.3	-0.8	123.6	-1.7
1045	98.6	-0.7	106.1	-1.2	112.0	-11.6
1100	99.6	1.0	104.6	-1.5	88.8	-23.2
1115	99.1	-0.5	104.3	-0.3	74.8	-14.0
1130	98.9	-0.2	104	-0.3		
1145	99.0	0.1	101.2	-2.8		
1200	96.9	-3.1	96.8	-4.4		
1215	97.8	0.9	90.3	-6.5		
1230	91.3*	-6.5	83.4	-7.9		
1245	86.9	-4.4	74.9	-8.5		
1300	84.6	-2.3				
1315	80.9	-3.7				
1330	78.4	-2.5				
1345	76.2	-2.2				
1400	74.8	-1.4				

B.3 GTT OSCAR Test Data

Temperature testing was conducted for new and used targets, multiple times, and was averaged.

Table B-3. GTT OSCAR lab testing temperatures.

Temperature	New Target		Used Target	
Time	**F°**	**ΔT**	**F°**	**ΔT**
0900	74.8	0	74.8	0
0915	89.5	19.5	88.9	14.1
0930	92.7	3.2	94.4	6.5
0945	92.9	0.2	95.3	2.9
1000	93.1	0.2	95.7	0.9
1015	93.4	0.3	95.4	0.2
1030	93.3	-0.1	95.3	-0.1
1045	93.6	0.3	96.6	-0.7
1100	93.6	0	95.6	-1.0
1115	93.1	-0.5	96.1	-0.5
1130	93.9	0.8	95.9	-0.2
1145	93.0	-0.9	95.0	-0.9
1200	93.9	0.9	95.9	0.9
1215	93.8	-0.1	95.8	-0.1
1230	93.3	-0.5	96.3	0.5
1245	92.9	-0.4	95.9	-0.4
1300	93.6	0.7	95.6	-0.3
1315	92.9	-0.7	95.9	0.3
1330	93.4	0.5	94.4	-1.5
1345	93.2	-0.2	94.2	-0.2
1400	92.8	-0.4	94.8	0.6
1430	91.1	-1.7	92.8	-2.0
1445	90.6	-0.5	91.3	-1.5
1500	89.8	-0.8	90.3	-1.0